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ADVANCEMENTS IN CRYOGENIC COOLERS

Maintenance-free cooling technology to meet the requirements of demanding applications

INTRODUCTION

From homeland security to medical imaging to space exploration, cryogenic coolers play a key role. There are countless applications and instruments that require deep cold to function properly and provide optimal performance. Unfortunately, commonly available cooling technologies consume large amounts of power, provide limited cooling capacity, and require regular maintenance. RIX's unique acoustic-Stirling cryocoolers combine mechanical simplicity, robustness and efficiency while using an environmentally friendly refrigerant. This paper details the basic operation of these "green" systems and the advantages they offer.

Figure 1: RIX Cryogenic Cooler

PROBLEMS ASSOCIATED WITH EXISTING TECHNOLOGIES

Conventional small scale cryocoolers include complicated Gifford-McMahon (G-M) and kinematic Stirling technologies with close-fit, dry-rubbing wear parts in the sensitive cold areas. These systems have reached development limits without achieving the performance or reliability required for most demanding commercial applications. Now, with RIX acoustic cryogenic refrigeration systems, with unit capacities of a few watts to over a kilowatt at 77K, there are affordable, no-maintenance options available for a variety of different applications.

The G-M cooler shown in Figure 2 uses a conventional oiled gas compressor to supply a steady stream of compressed helium to a cold head which is then expanded with mechanically driven valves and displacers. These cryocoolers are often used for temperatures well below 77K but, because of the valve wear and oil in the compressors, they require regular still on a level surface, making them unsuitable for some military and aerospace installations. In addition, the significant noise and vibration they produce cannot be tolerated in many laboratory and sensitive applications.

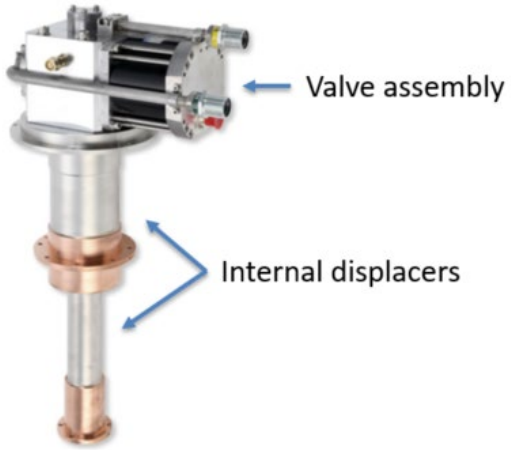

Figure 2: G-M style coldhead with valves and displacers
Source: https://www.stirlingcryogenics.eu/en/the-stirling-cycle

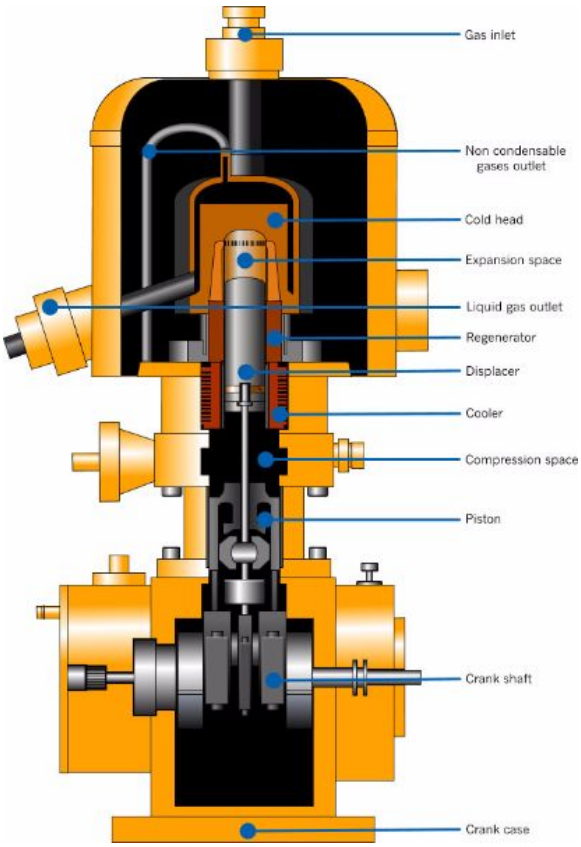

Figure 3: Typical kinematic Stirling cryocooler with mechanical linkage and cold-end displacer

Kinematic Stirling cryocoolers also use a mechanical displacer in the cold region of the cryocooler and have an oil reservoir to lubricate the crank shaft and linkage (see Figure 3). Typically these systems provide decent efficiency but also produce significant noise and vibration. In addition to friction wear, over time the oil migrates to the cold area and regenerator, reducing efficiency and cooling power, which forces a complete rebuild approximately every 8,000-10,000 hours of operation.

THE SOLUTION

RIX's thermoacoustic Stirling cryocoolers have no cold moving parts or internal wear components. When driven by sealed, oil-free, linear motors with flexure bearings, they offer an excellent option to meet the demands of many applications. Thermodynamically similar to G-M and kinematic Stirling machines, they achieve comparable performance without the life-limiting mechanical displacers by using a tuned acoustic network of tubing and chambers that cause the working fluid's own inertia and compressibility properties to mimic the displacer's effect.

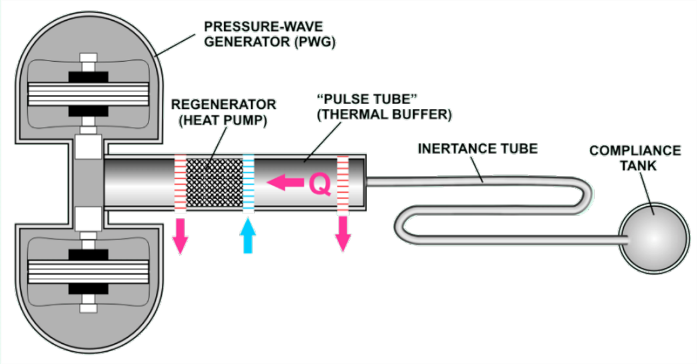

Figure 4: Simplified diagram of a thermoacoustic cryocooler

A RIX cryocooler consists of a pressure wave generator driven by two linear reciprocating motors and a thermoacoustic Stirling coldhead. The coldhead consists of a warm heat exchanger, a regenerator, a cold heat exchanger, a thermal buffer tube, a hot heat exchanger, an inertance tube, and a compliance tank. Figure 4 shows an inline cryocooler configuration for simplicity, but actual coldheads are "folded over" at the cold heat exchanger to expose the cold zone for easy integration.

The heart of RIX's long-life, no-maintenance technology is the resonant linear reciprocating motors. These have a unique wear-free suspension system, with unlimited life and pure single-axis motion. This eliminates contact between moving parts and associated lubrication requirements. RIX motors utilize an innovative interdigitating moving magnet design with robust coil-over-iron stators (see Figure 5 below). Each model is designed to operate for well over 10 maintenance-free years with a calculated mean time between failure of 129,760 hours per MIL-STD 217F standards. This is supported by the performance of 100's of installations worldwide.

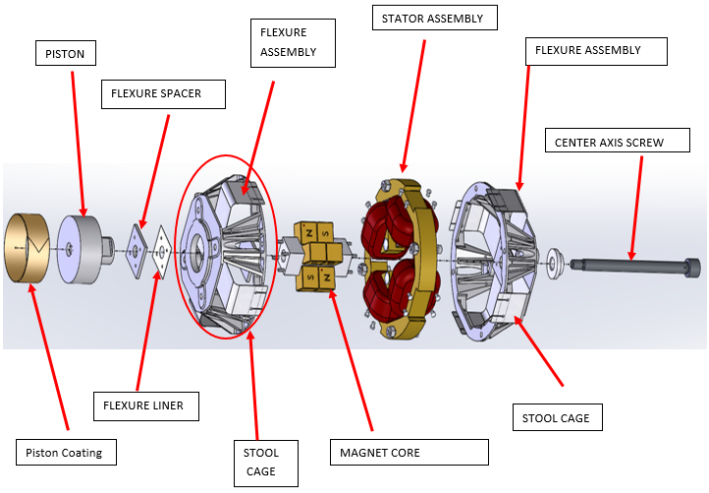

Figure 5: Basic components of a RIX linear motor

Typical refrigeration systems require the compression and expansion of a gas with heat exchangers to move heat from one location to another. Normally, the compression is accomplished using rotary compressors like what you find in most home refrigerators and freezers. In these systems the refrigerant is in direct contact with the lubricating oil which allows the oil to migrate outside of the compressor area. This can generally be tolerated at warmer than cryogenic temperatures, however, at extremely low temperatures the oil can freeze and foul heat exchangers. To eliminate this problem RIX utilizes and oil-free pressure wave generator (PWG).

These are valveless electroacoustic devices, like extremely powerful audio speakers, that produce high-intensity acoustic power. They are designed to alternately compress and expand inert gases to drive loads such as thermoacoustic Stirling cryocoolers. Each PWG consists of two linear motors mounted "nose-to-nose" within a common pressure vessel (see Figure 6). The opposing motors not only double the amount of acoustic power generated in each stroke they also balance the system by operating in opposition, significantly reducing vibration.

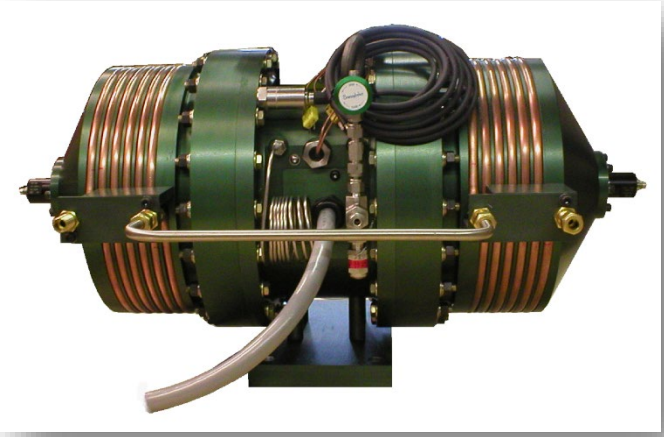

Figure 6: Water cooled pressure wave generator

By combining an oil-free PWG and thermoacoustic Stirling coldhead with no moving parts, you create a cryocooler that offers low vibration and virtually unlimited life. This technology can also be frequently started and stopped without concern of overheating the motors. In addition, the input power can be modulated on-the-fly to match fluctuating cooling demands, significantly reducing power consumption. RIX has packaged several combinations of these devices, offering a family of standard cryocoolers that cover a wide range of cooling powers. Table 1 below outlines the various models and their specifications, however, custom systems are also offered and larger systems are under development.

Cooler Model	2s102K	2s132K	2s175K*	2s226K	2s241K	2s362K*
Capacity @ 77K (W)	6–8	17–20	50	150	220	1,000
Capacity @ 150K (W)	27	70	175	400	950	2,400
No load temperature (K)	50	45	50	37	50	40
Power consumption @ rated condition (W)	275	600	1,500	2,750	4,500	22,000
Electrical requirements**	110Vac max., 1Φ, 60Hz	110Vac max., 1Φ, 60Hz	110Vac max., 1Φ, 60Hz	208Vac max., 1Φ, 60Hz	208Vac max., 1Φ, 60Hz	380Vac max., 1Φ, 60Hz
Maximum operating current (amps)	4.25	9	16	30	40	80
Ambient operating temperature	32°-90°F (0°-32°C)	32°-90°F (0°-32°C)	32°-90°F (0°-32°C)	32°-90°F (0°-32°C)	32°-90°F (0°-32°C)	32°-90°F (0°-32°C)
Maintenance Interval	None	None	None	None	None	None
Rejection method	H_2O or Air	H_2O or Air	H_2O	H_2O	H_2O	H_2O
Cooling flow rate (for water cooled units)	1 liters/min	2 liters/min	4 liters/min	10 liters/min	12 liters/min	50 liters/min

All specification subject to change
* Units under development. Specifications estimated
** Nominal for standard unit. Custom voltage and frequency available

Table 1: Standard RIX cryocooler models and specifications

CONCLUSION

By eliminating the use of CFC refrigerants and using helium as the working fluid, all RIX cryocoolers are environmentally friendly devices. Combine that with the complete absence of moving parts in the cold areas, and the oil-free design, these coolers offers significant advantages over G-M and kinematic designs. Based on these advantages, the lack of required maintenance, the single push button start, and the ability to reach cryogenic temperatures in under 20 minutes, the US Navy has standardized on RIX systems for their liquid oxygen plants on all Ford-class aircraft carriers. RIX is proud to be such a valued, respected and critical supplier to our armed forces. We are also proud to support hundreds of commercial installations worldwide with our unique devices.

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